THE TIMED TELEMETRY DEFINITION SYSTEM

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ABSTRACT

Specifying and maintaining spacecraft telemetry definitions has historically been an arduous task. As telemetry locations, mnemonics, conversions, and additional information are defined, they are typically assembled into a collection known as a telemetry dictionary. The definition in the telemetry dictionary ultimately provides a means for the ground system to appropriately decommutate and display spacecraft telemetry and additional ground system information (for example, ground support equipment status). The telemetry dictionary typically consists of one or more formatted files or a series of tables in a database, depending on the ground system implementation. Most recent missions that The Johns Hopkins University Applied Physics Laboratory has participated in used a database for their telemetry definition. Population of the database involved manual entry of the information into specific database tables through a form-based graphical user interface. Although this type of interface is effective, it is prone to entry errors and provides rollbacks of limited use.

For the National Aeronautics and Space Administration's (NASA) Thermosphere, Ionosphere, Mesosphere, Energetics and Dynamics (TIMED) mission, a new means of building and maintaining the telemetry dictionary has been developed. The TIMED Telemetry Definition System (TTDS) has improved the reliability of database updates by providing well-structured user-populated spreadsheets and a web-based interface to submit new or updated telemetry definitions. Users may submit telemetry workbooks via a web interface for cognizant members of the Mission Operations Team to review, promote for database inclusion, or demote due to errors or improper adherence to telemetry definition conventions.

The TTDS supports users at various controlled levels, allowing restricted access to Spacecraft and Integration and Test (I&T) Engineers (submit, status), with expanded access to Mission Operations Spacecraft Specialists (submit, status, review, reject, pending). All users have access to the current telemetry definition for download, including access to configuration-managed archives of previous versions of the telemetry packet workbooks. The system bridges the user-definition of telemetry on a PC or Macintosh with the UNIX workstation database population.

This paper will provide details of the TTDS design and distributed implementation, along with a discussion of the development tools used. In addition, the paper will discuss the success and expansion of this system, through the first year of on-orbit TIMED mission operations, and to multi-mission use for upcoming NASA missions.

1. INTRODUCTION

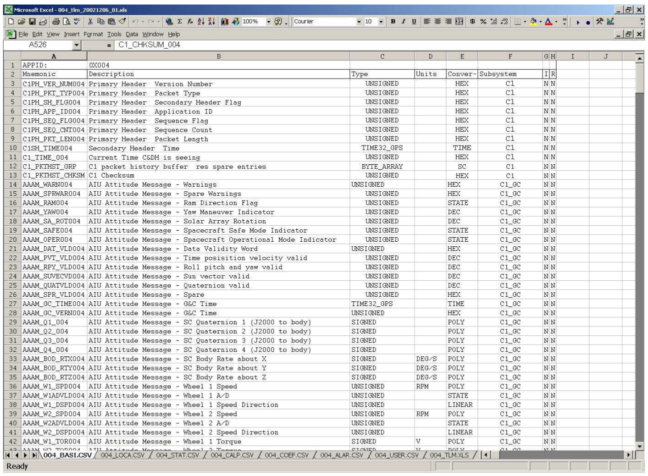
Early in the development of the TIMED Ground System, The Johns Hopkins University (JHU) Applied Physics Laboratory (APL) selected the EPOCH 2000 Commercial Off the Shelf (COTS) core ground system from Integral Systems Inc. (ISI). This core system was also successfully used at APL for the Near Earth Asteroid Rendezvous (NEAR) mission. The ISI design provided an Oracle database for command and telemetry definition, with an Oracle Forms interface by which Mission Operations and Integration and Test personnel could assemble the data dictionary. ISI also provided software to extract the command and telemetry definitions from the database and translate them to a flat ASCII file. During the EPOCH startup sequence, the user is prompted for the name of the flatfile to use for the session. This flatfile is then loaded by EPOCH to system memory on startup.

A lesson learned from NEAR was that the population of the telemetry database was effective through this means, but was particularly time consuming. Commands were built through the Oracle Forms interface as well, but there were substantially fewer commands than telemetry points, so the telemetry definition became the focus for an improvement.

Throughout this paper items in *italics* refer to subdirectories in the TTDS FTP Server structure. Underlined items refer to software components of the TTDS.

2. THE TELEMETRY WORKBOOK

Members of the Ground System Development Team devised a means of bypassing the manual entry of telemetry definition parameters into Oracle. The concept consisted of entering the telemetry definitions into a Microsoft Excel workbook, and then creating comma separated value (CSV) files, transferring the files from the PC or Macintosh to the Unix workstation containing the Oracle database, and then running a Unix executable that ingested the CSV files into the Oracle database. Through interpretation of the Oracle database tables and relationships provided by ISI, the Developers created the Telemetry Workbook and several Unix routines. A worksheet from a sample TIMED Telemetry Definition Workbook is shown in Figure 1.



	A	B	C	D	E	F	G	H
1	APPID:	0X004						
2	Mnemonic	Description	Type	Units	Conver-	Subsystem	I	R
3	C1PH_VER_NUM004	Primary Header Version Number	UNSIGNED		HEX	C1	N	N
4	C1PH_PKT_TYP004	Primary Header Packet Type	UNSIGNED		HEX	C1	N	N
5	C1PH_SH_FLG004	Primary Header Secondary Header Flag	UNSIGNED		HEX	C1	N	N
6	C1PH_APP_ID004	Primary Header Application ID	UNSIGNED		HEX	C1	N	N
7	C1PH_SEQ_FLG004	Primary Header Sequence Flag	UNSIGNED		HEX	C1	N	N
8	C1PH_SEQ_CNT004	Primary Header Sequence Count	UNSIGNED		HEX	C1	N	N
9	C1PH_PKT_LEN004	Primary Header Packet Length	UNSIGNED		HEX	C1	N	N
10	C1SH_TIME004	Secondary Header Time	TIME32_GPS		TIME	C1	N	N
11	C1_TIME_004	Current Time C&DH is seeing	UNSIGNED		HEX	C1	N	N
12	C1_PKTHST_GRP	C1 packet history buffer res spare entries	BYTE_ARRAY		SC	C1	N	N
13	C1_PKTHST_CHKSM	C1 Checksum	UNSIGNED		HEX	C1	N	N
14	AAAM_WARN004	AIU Attitude Message - Warnings	UNSIGNED		HEX	C1_GC	N	N
15	AAAM_SPRWAR004	AIU Attitude Message - Spare Warnings	UNSIGNED		HEX	C1_GC	N	N
16	AAAM_RAM004	AIU Attitude Message - Ram Direction Flag	UNSIGNED		STATE	C1_GC	N	N
17	AAAM_YAW004	AIU Attitude Message - Yaw Maneuver Indicator	UNSIGNED		DEC	C1_GC	N	N
18	AAAM_SA_ROT004	AIU Attitude Message - Solar Array Rotation	UNSIGNED		DEC	C1_GC	N	N
19	AAAM_SAFE004	AIU Attitude Message - Spacecraft Safe Mode Indicator	UNSIGNED		STATE	C1_GC	N	N
20	AAAM_OPER004	AIU Attitude Message - Spacecraft Operational Mode Indicator	UNSIGNED		STATE	C1_GC	N	N
21	AAAM_DAT_VLD004	AIU Attitude Message - Data Validity Word	UNSIGNED		HEX	C1_GC	N	N
22	AAAM_PVT_VLD004	AIU Attitude Message - Time posisition velocity valid	UNSIGNED		DEC	C1_GC	N	N
23	AAAM_RPY_VLD004	AIU Attitude Message - Roll pitch and yaw valid	UNSIGNED		DEC	C1_GC	N	N
24	AAAM_SUVECVD004	AIU Attitude Message - Sun vector valid	UNSIGNED		DEC	C1_GC	N	N
25	AAAM_QUATVLD004	AIU Attitude Message - Quaternion valid	UNSIGNED		DEC	C1_GC	N	N
26	AAAM_SPR_VLD004	AIU Attitude Message - Spare	UNSIGNED		HEX	C1_GC	N	N
27	AAAM_GC_TIME004	AIU Attitude Message - G&C Time	TIME32_GPS		TIME	C1_GC	N	N
28	AAAM_GC_VERN004	AIU Attitude Message - G&C Time	UNSIGNED		HEX	C1_GC	N	N
29	AAAM_Q1_004	AIU Attitude Message - SC Quaternion 1 (J2000 to body)	SIGNED		POLY	C1_GC	N	N
30	AAAM_Q2_004	AIU Attitude Message - SC Quaternion 2 (J2000 to body)	SIGNED		POLY	C1_GC	N	N
31	AAAM_Q3_004	AIU Attitude Message - SC Quaternion 3 (J2000 to body)	SIGNED		POLY	C1_GC	N	N
32	AAAM_Q4_004	AIU Attitude Message - SC Quaternion 4 (J2000 to body)	SIGNED		POLY	C1_GC	N	N
33	AAAM_BOD_RTX004	AIU Attitude Message - SC Body Rate about X	SIGNED	DEG/S	POLY	C1_GC	N	N
34	AAAM_BOD_RTY004	AIU Attitude Message - SC Body Rate about Y	SIGNED	DEG/S	POLY	C1_GC	N	N
35	AAAM_BOD_RTZ004	AIU Attitude Message - SC Body Rate about Z	SIGNED	DEG/S	POLY	C1_GC	N	N
36	AAAM_W1_SPD004	AIU Attitude Message - Wheel 1 Speed	UNSIGNED	RPM	POLY	C1_GC	N	N
37	AAAM_W1ADVLD004	AIU Attitude Message - Wheel 1 A/D	UNSIGNED		STATE	C1_GC	N	N
38	AAAM_W1_DSPD004	AIU Attitude Message - Wheel 1 Speed Direction	UNSIGNED		LINEAR	C1_GC	N	N
39	AAAM_W2_SPD004	AIU Attitude Message - Wheel 2 Speed	UNSIGNED	RPM	POLY	C1_GC	N	N
40	AAAM_W2ADVLD004	AIU Attitude Message - Wheel 2 A/D	UNSIGNED		STATE	C1_GC	N	N
41	AAAM_W2_DSPD004	AIU Attitude Message - Wheel 2 Speed Direction	UNSIGNED		LINEAR	C1_GC	N	N
42	AAAM_W1_TOR004	AIU Attitude Message - Wheel 1 Torque	SIGNED	V	POLY	C1_GC	N	N

Figure 1. TIMED Telemetry Workbook for APID 0X004

TIMED engineers followed a CCSDS recommendation for packetized telemetry, and further chose to select fixed length packets. Each telemetry packet was assigned a unique Application ID (APID). As a result, the definition of each APID was through it's own telemetry workbook. The workbook would consist of seven distinct worksheets. The type of information provided in each worksheet, including the worksheet name (in parenthesis) is as follows:

Basic (BASI) – This worksheet contained basic information about telemetry points within the APID packet, including the telemetry mnemonic, a description of the telemetry point, data type (signed, unsigned, byte_array, etc.), units (deg, poly, hex, state, etc.) and conversion (hex, state, poly, time, etc.). The mnemonics are repeated throughout the other sheets of the APID's workbook;

Location (LOCA) – This worksheet includes the starting byte, starting bit and the number of bits to define the telemetry point. Additional decommutation information is included on this sheet, such as related context points and values for subcommutated telemetry;

State (STAT) – This worksheet includes state values and their related state messages (for example, 0=OFF, 1=ON), including context-relevant switch points;

Calibration Pairs (CALP) – This worksheet includes calibration information (both raw and engineering units) in a piece-wise linear fashion (for example, raw data values between A and B should use the calibration X, raw data values between B and C should use the calibration Y, etc.);

Calibration Coefficients (COEF) – This worksheet uses polynomial coefficients for calibration of the raw telemetry data;

Alarm (ALAR) – This worksheet includes green, yellow, and red alarm limits for the telemetry points in the packet, switch points, and range (inclusive, exclusive), and

User (USER) – This worksheet contains general user comments pertinent to the APID.

3. LOADING THE WORKBOOK DATA

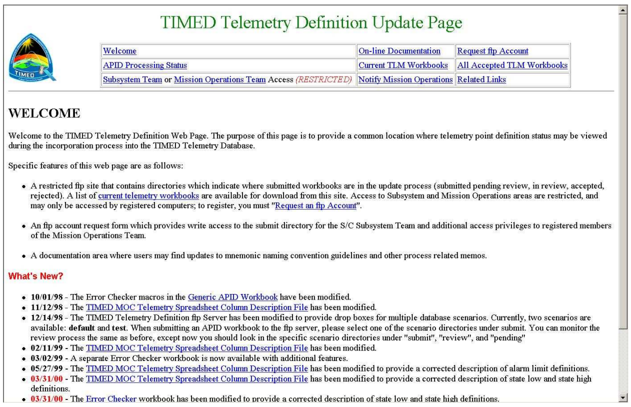
To facilitate transfer of information from the telemetry workbook to the Oracle database, additional manual steps needed to occur. First, the workbook needed to be split into seven distinct CSV files. This was accomplished by creating an Excel macro to generate the CSV files. Next, the files needed to be transferred from the PC-domain to the Unix-domain via FTP. Then, the CSV files needed to be properly loaded into Oracle. This was accomplished through the creation of an Oracle Pro-C executable called tlm load. The tlm load program was executed from the Unix command line, with the appropriate calling arguments of a hexadecimal APID number and the desired database scenario to load the definitions to for a given spacecraft. The spacecraft/scenario capability was provided by ISI to allow for multiple spacecraft and multiple test and operational instances. For example, a TEST scenario was envisioned for bench level testing by the spacecraft subsystem engineers, and a DEFAULT scenario was used by Integration and Test as components were staged for integration on the spacecraft bus. Upon successful processing of all APID workbooks, a flatfile could be generated for system test.

This process provided a marked improvement over the Oracle Forms input method, but quickly exposed new areas for improvement. In particular, since the workbook concept allowed the subsystem engineering team to build telemetry definitions, it was necessary to properly train the team to adhere to a uniform set of standards and naming conventions while building the workbooks. This included the standard primary and secondary packet header that was applied to every telemetry packet for TIMED. Training of the subsystem engineering team was accomplished through the use of documented standards and training sessions with I&T personnel and Mission Operations Spacecraft Specialists. The Spacecraft Specialists were Mission Operations team members who were specifically assigned to gain expertise in the Command and Data Handling System (C&DH), the Guidance and Control System (G&C), and the Global Positioning System (GPS) Navigation System (GNS).

With the distributed telemetry definition across a broad team of individuals came a large quantity of telemetry packet definitions, and the need to properly monitor their validity and inclusion into the telemetry dictionary.

4. THE TELEMETRY DEFINITION SYSTEM

A system was devised to monitor the incoming telemetry definitions from the engineering team and facilitate their loading to the Oracle database. To provide a focal point for the process, a web interface was created to provide a remote input drop-box for submission of workbooks. The web interface also contained links to documentation, account requests, status information, and tools to assist in the workbook creation process. The web pages were created with Microsoft FrontPage and a web server set up on a low-cost Windows-based PC. A sample screen of the top-level web interface is shown in Figure 2.


TIMED Telemetry Definition Update Page

Welcome	On-line Documentation	Request ftp Account
APID Processing Status	Current TLM Workbooks	All Accepted TLM Workbooks
Subsystem Team or Mission Operations Team Access *(RESTRICTED)*	Notify Mission Operations	Related Links

WELCOME

Welcome to the TIMED Telemetry Definition Web Page. The purpose of this page is to provide a common location where telemetry point definition status may be viewed during the incorporation process into the TIMED Telemetry Database.

Specific features of this web page are as follows:

- A restricted ftp site that contains directories which indicate where submitted workbooks are in the update process (submitted pending review, in review, accepted, rejected). A list of current telemetry workbooks are available for download from this site. Access to Subsystem and Mission Operations areas are restricted, and may only be accessed by registered computers; to register, you must "Request an ftp Account".
- An ftp account request form which provides write access to the submit directory for the S/C Subsystem Team and additional access privileges to registered members of the Mission Operations Team.
- A documentation area where users may find updates to mnemonic naming convention guidelines and other process related memos.

What's New?

- **10/01/98** - The Error Checker macros in the Generic APID Workbook have been modified.
- **11/12/98** - The TIMED MOC Telemetry Spreadsheet Column Description File has been modified.
- **12/14/98** - The TIMED Telemetry Definition ftp Server has been modified to provide drop boxes for multiple database scenarios. Currently, two scenarios are available: **default** and **test**. When submitting an APID workbook to the ftp server, please select one of the scenario directories under submit. You can monitor the review process the same as before, except now you should look in the specific scenario directories under "submit", "review", and "pending"
- **02/11/99** - The TIMED MOC Telemetry Spreadsheet Column Description File has been modified.
- **03/02/99** - A separate Error Checker workbook is now available with additional features.
- **05/27/99** - The TIMED MOC Telemetry Spreadsheet Column Description File has been modified to provide a corrected description of alarm limit definitions.
- **03/31/00** - The TIMED MOC Telemetry Spreadsheet Column Description File has been modified to provide a corrected description of state low and state high definitions.
- **03/31/00** - The Error Checker workbook has been modified to provide a corrected description of state low and state high definitions.

Figure 2. The Telemetry Definition Homepage

Workbooks are submitted through this web site (via FTP) into a directory structure as shown in Figure 3. The subsystem engineering team has limited write access to this directory structure, and can only submit workbooks to the scenario(s) under the *submit* directory. A process running on the Windows PC called the Workbook Watchdog monitors for workbook submissions to the *submit* directories.

Upon workbook arrival, Workbook Watchdog determines which system the APID is associated with and looks up a list of cognizant Mission Operations members who need to be notified of the submission. The Workbook Watchdog then moves the workbook to the appropriate scenario in the *review* directory and sends an email to the appropriate personnel. In addition, the Workbook Watchdog may be configured to sound an audible alert in the Mission Operations Center to indicate an APID is ready for review.

The review process was designed to include a checkpoint where Mission Operations oversight provides coordinated validation of workbooks submitted by the engineering team. A software tool called the Error Checker is available to assist the Mission Operations team (and is also available to the spacecraft engineering team) in searching for errors in the workbooks. This tool, written in Visual Basic for Applications, is available for use on PC and Macintosh platforms in it's own Microsoft Excel workbook, so updates are easily distributed. The Error Checker Graphical User Interface (GUI) is shown in Figure 4.

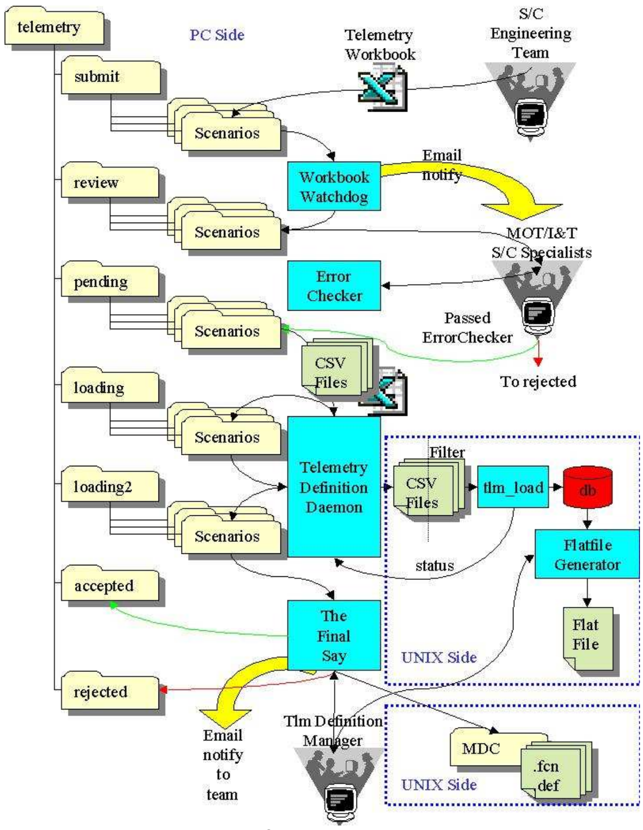


Figure 3. Telemetry Definition System Structure

If the Mission Operations Spacecraft Specialists cannot resolve the errors, the workbook is moved to the *rejected* directory and notification is sent to the submitter of the workbook. If no errors are found, Mission Operations personnel move the workbook to the appropriate scenario in the *pending* directory.

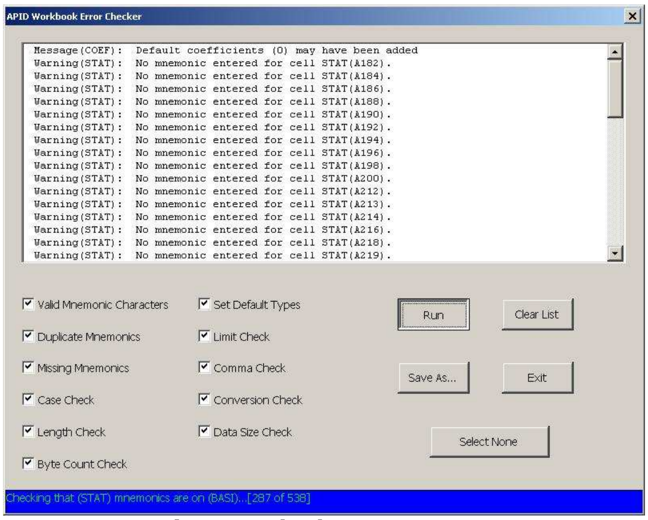


Figure 4. Sample Error Checker Session

Once a workbook is placed in a pending subdirectory, the Telemetry Definition Daemon (or TDD) begins the process that ultimately loads the definitions into the Oracle database. During this process, the workbook and additional generated components are moved through the corresponding scenario subdirectories under *loading* and *loading2* using components of the Telemetry Definition Daemon called the Controller and Shelled. Figure 5 shows the GUI for the Controller component that runs on the Telemetry Definition PC. First, the seven worksheets within the workbook are saved as CSV files. Next, a telnet session is initiated by the Shelled component (shown in Figure 6) with the Unix system where Oracle resides. The CSV files are sent via Shelled using FTP to the Unix system, where a filtering process (a C program called Filter) further refines the contents of the files for consistency during the database load process. For example, it is acceptable to have a single mnemonics record on the *STAT* sheet of the workbook, followed by multiple state entries without an explicit mnemonic name. This allows for a visually easier worksheet for the user to navigate. Filter adds this mnemonic to all related records in the CSV file for proper loading to Oracle.

Figure 5. The TDD Controller GUI

Once Filter has completed execution, the Telemetry Definition Daemon checks to see if tlm load is ready to begin. The tlm load program must be run in series, since only one instance of it can run at a time. The Telemetry Definition Daemon serves as a gatekeeper to monitor the tlm load status and process a queue of awaiting workbooks. If tlm load is not running, then the Daemon may start it through the Shelled telnet session. The custom telnet client portion of Shelled is visible on the Telemetry Definition PC in the Mission Operations Center, and can be viewed at any time to see status of the loading process. Status information from tlm load is displayed on the Shelled telnet client window, and is monitored by other portions of the Daemon. Upon completion of tlm load, the Daemon will cycle back to the pending subdirectories to look for more workbooks, and the process repeats itself. This allows for a quantity of workbooks to be processed throughout the day in an unattended mode.

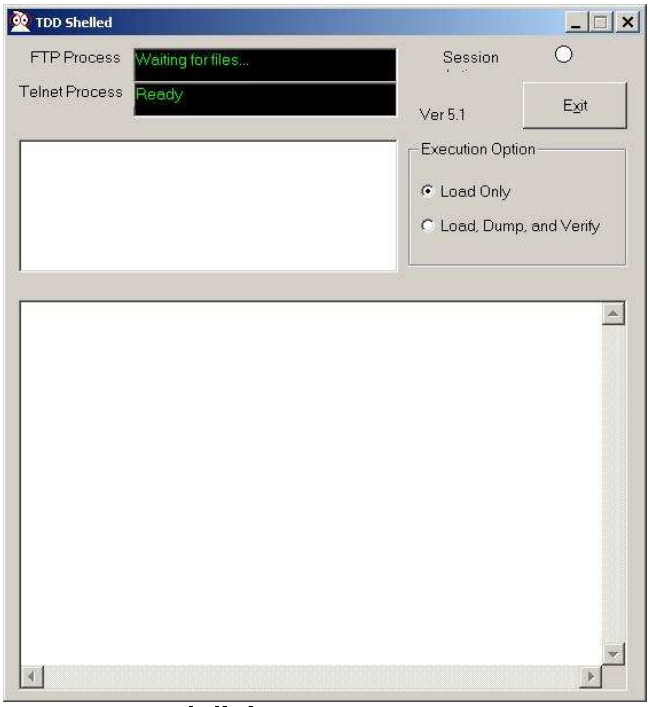


Figure 6. TDD Shelled Session GUI

The Load Log Checker, another PC-based software component, analyzes the status information that is produced by the Telemetry Definition Daemon. The Telemetry Definition Manager (an oversight role performed by the Mission Operations Manager) reviews this information. Any errors encountered in the database load process are called out in this log. This allows Mission Operations to either correct the error (and resubmit the corrected APID workbook) or reload the previously accepted version of the APID workbook. The Graphical User Interface (GUI) for the Load Log Checker is shown in Figure 7.

Once all submitted workbooks are processed during a session, the Telemetry Definition Manager locks access to the Oracle database and initiates the generation of a command and telemetry flatfile. The flatfile generation process is provided by ISI and is command line initiated.

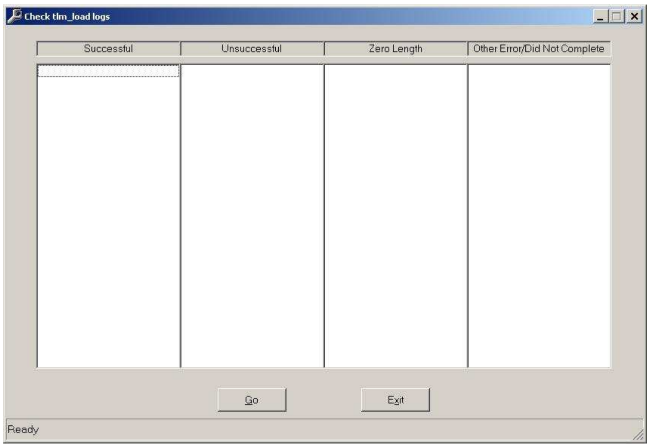


Figure 7. The Load Log Checker GUI

Upon successful completion of flatfile generation, the Telemetry Definition Manager uses EPOCH 2000 in the TIMED simulator environment to test the flatfile. The EPOCH streams are started and connected to the TIMED Operations Simulator (TOPS), which is a hardware-in-the-loop simulator consisting of engineering model spacecraft components coupled with space environment simulated inputs. These simulated inputs include a GPS simulator, the TIMED Attitude System Test and Integration Environment (TASTIE), and a testbed providing simulated telemetry from the onboard instruments.

After successful test, and the approval of the TIMED Configuration Control Board (CCB), the flatfile (and ancillary files generated during the process) are moved to the operational environment. The Telemetry Definition Manager then releases the new flatfile for operational use by the Mission Operations Team.

To complete the acceptance process, the Telemetry Definition Manager utilizes another component of the Telemetry Definition System called <u>The Final Say</u>. This PC-based software component (shown in Figure 8) is used to associate the processed telemetry workbooks with the newly generated and released flatfile. Upon association, <u>The Final Say</u> performs a number of tasks. The workbook(s) that have been successfully processed are moved to the *accepted* directory, and an indexed file of accepted workbooks is updated for each related scenario. This file may be accessed from the Telemetry Definition Webpage to retrieve the most recent workbook for a given APID/scenario, and is the starting point for future updates to the telemetry definition.

<u>The Final Say</u> also sends the new telemetry definitions to the instrument community through the TIMED Mission Data Center (MDC). The CSV files are renamed with a .def extension (to indicate definition files), and a .fcn (file change notification) file is created. The .def and .fcn files are then sent via FTP to an MDC system that is accessible external to APL. This provides access for members of the instrument teams located at the TIMED Payload Operations Centers (POCs). These POCs, located at University of Colorado, University of Michigan Ann Arbor, NASA Langley, Utah State University, and APL interpret these files and update their ground system components accordingly to properly decommutate TIMED telemetry.

Another feature of <u>The Final Say</u> is e-mail notification of appropriate TIMED personnel based on APID groupings. A PC-resident database of APIDs relates groups of team members that need to be notified upon successful promotion of new telemetry workbook(s) for approved use, or to signal rejection of the workbook(s). For example, notification for workbooks pertaining to G&C will be sent to members of the G&C team and others people listed as “Notify-G&C” in the database notification table.

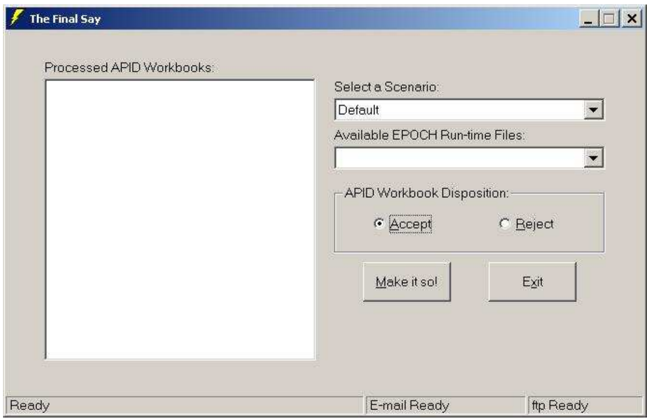


Figure 8. The Final Say GUI

5. FUTURE MISSION EXPANSION

The TIMED Telemetry Definition System successfully processed and managed multiple scenarios of telemetry definitions, with some scenarios exceeding 60,000 telemetry points each during the evolution of the mission. TIMED was launched on December 7, 2001, and continues to successfully support all of the science objectives of the mission. The automated portion of the Telemetry Definition System was developed by members of the TIMED Mission Operations Team at a fractional level of effort over the course of approximately one year. Since Mission Operations was the ultimate end user of this system, it was highly effective to include members of this team in the development of the TTDS. Low cost Microsoft development tools such as Access, Visual Basic, Excel, FrontPage, and Web Server, coupled with cost efficient PCs (a Pentium III 450MHz with 40Gb RAID-1 disk drives and

512Mb of RAM still used today as the Telemetry Definition Server) simplified development and integration with the small number of Unix-resident components of the system.

The success of this system, its ease of expandability, and simple deployment on low-cost PCs made the TTDS a desirable component to include in other NASA missions conducted at APL. As a result, the scope of telemetry definition expanded within the APL Space Department's Integration and Operations Group to include the TTDS as its core telemetry definition system. The system was utilized on the Comet Nucleus Tour (CONTOUR) mission, and has evolved to multi-mission implementation for the following NASA missions currently under development:

- The Mercury Surface, Space Environment, Geochemistry, and Ranging Mission (MESSENGER);
- The Solar Terrestrial Relations Observatory Mission (STEREO), and
- The New Horizons Pluto-Kuiper Belt Mission.

The multi-mission Telemetry Definition System has been enhanced to include command definitions as well. Command definitions were not included in the original system deployment for TIMED based on budget and schedule considerations, but fortunately have been added to the multi-mission system. Administration and monitoring of this multi-mission system for the above set of APL missions, as well as developer support for enhancements and maintenance, are accomplished at a full-time equivalent (FTE) staffing rate of less than 1.5 work-years/year.

Possible future enhancements to the current multi-mission Command and Telemetry Definition System may involve a direct translation of telemetry definitions in Excel workbooks to an EPOCH-compliant flatfile. Investigation into ancillary data separately defined in the Oracle database may provide for its definition outside of the Oracle environment. This would provide both a time and cost savings in the command and telemetry definition process.

6. ACKNOWLEDGEMENTS

The Author wishes to acknowledge the contributions of several individuals in the evolution of the TIMED Telemetry Definition System. William Dove and Walter Mitnick of the TIMED Ground System Development Team devised the original structure of the telemetry workbooks. Walter Mitnick also created the tlm load software and related Pro C routines. Michael Packard of the TIMED Mission Operations Team developed the Unix-resident Filter software. Rob Sadler, formerly of Integral Systems Inc., developed the flatfile generation software and provided the Oracle database design for TIMED. The Author designed, developed, and implemented all remaining software components, including Webpage design, the Web and FTP server configurations, and the PC configuration.

The Author would also like to acknowledge Lisa Segal, who aptly learned the TIMED Telemetry Definition System and continues to provide development and daily operational support for the multi-mission system.